

The invention in which an exclusive right is claimed is defined by the following:

1. A modular system for producing a desired chemical product from a plurality of reactants comprising:

(a) a control module, said control module being adapted to monitor and control production of the desired chemical product by the modular system;

(b) a reactant supply source for each of said plurality of reactants, a flow of each reactant from its reactant supply source being controlled by the control module; and

(c) a first reaction module in fluid communication with each reactant supply source to receive each of the plurality of reactants, said first reaction module being controllably connected to said control module and including a replaceable reactor, said replaceable reactor automatically producing the desired chemical product from said plurality of reactants under the control of the control module.

2. The modular system of Claim 1, wherein said replaceable reactor comprises a mixing volume and a reaction volume.

3. The modular system of Claim 1, wherein at least one of said plurality of reactants is in a gaseous state.

4. The modular system of Claim 1, further comprising a pump module controllably connected to the control module, said pump module being in fluid communication with each reactant supply source and with said first reaction module, the pump module pumping at least one fluid through the modular system.

5. The modular system of Claim 1, further comprising an additional processing module in fluid communication with said first reaction module.

6. The modular system of Claim 5, wherein said additional processing module comprises a residence time module in which reaction of the desired chemical product continues toward completion for a predetermined amount of time.

7. The modular system of Claim 6, wherein said residence time module comprises a capillary passage of a length selected to obtain the predetermined amount of time for said desired chemical product in said residence time module.

8. The modular system of Claim 6, wherein said residence time module comprises a proportional valve, said proportional valve being controllably connected to said control module to selectively vary a pressure within said modular system.

9. The modular system of Claim 5, wherein said additional processing module comprises a second reaction module in fluid communication with said first reaction module, such that a serial fluid path is created with respect to said first reaction module, said additional reaction module being controllably connected to said control module and including a replaceable reactor that produces the desired chemical product from a reaction of said plurality of reactants, so that said modular system produces said desired chemical product using a plurality of synthesis steps, a first synthesis step being completed in said first reaction module, and a second synthesis step being completed in said additional reaction module.

10. The modular system of Claim 9, further comprising sufficient additional reaction modules so that production of the desired chemical product can be achieved using additional synthesis steps, each additional synthesis step being completed in an additional reaction module.

11. The modular system of Claim 1, wherein said replaceable reactor is specifically configured to enable it to produce a class of chemical products, and is selectively readily removable from said first reaction module and replaceable with a different replaceable reactor configured to facilitate the production of a different class of chemical products, thus enabling said modular system to selectively produce different classes of chemical products.

12. The modular system of Claim 5, wherein said first reaction module further includes a housing, said housing comprising:

- (a) a first side that includes a plurality of ports enabling said first reaction module to be removably connected to said control module and in fluid communication with said each reactant supply;
- (b) a second side that includes a plurality of ports enabling said first reaction module to be in fluid communication with at least one of the additional processing module and a product reservoir; and
- (c) a mounting frame for said replaceable reactor.

13. The modular system of Claim 1, wherein said first reaction module comprises means for facilitating production of said desired chemical product.

14. ~~The modular system of Claim 13, wherein said means include at least one of a heat exchanger, a temperature sensor, and a reactant laminar flow mixing passage.~~

15. ~~The modular system of Claim 1, wherein said control module comprises a memory, a processor, and a user interface, said memory storing machine instructions that are executed by the processor to effect automatic control of the modular system.~~

16. The modular system of Claim 1, wherein said modular system further comprises a plurality of fluid paths, including a fluid path for each of said plurality of reactants, a fluid path for said desired product, at least one fluid path for a heat transfer media, and at least one fluid path for a spent heat transfer media.

17. The modular system of Claim 1, wherein said at least one fluid path for said heat transfer media and said at least one fluid path for said spent heat transfer media are configured in one of a parallel fluidic system and a serial fluidic system.

18. The modular system of Claim 4, wherein said pump module comprises at least one pump, said at least one pump being controllably connected to said control module to control its operation.

19. The modular system of Claim 18, wherein said at least one pump is in fluid communication with both a heat transfer media fluid supply and said first reaction module.

20. The modular system of Claim 18, wherein said at least one pump is in fluid communication with both the reactant supply source for at least one of said plurality of reactants, and said first reaction module.

21. The modular system of Claim 4, wherein said pump module comprises a separate pump for each of said plurality of reactants, each separate pump being in fluid communication with the reactant supply for a different one of said plurality of reactants, and with said first reaction module.

22. The modular system of Claim 4, wherein said pump module comprises at least one valve, said at least one valve being controllably connected to said control module to control a flow of one of said plurality of reactants to said first reaction module.

23. The modular system of Claim 4, wherein said pump module comprises at least one filter that removes undesired material from one of said plurality of reactants before the reactant flows to said first reaction module.

24. The modular system of Claim 4, wherein said pump module comprises a housing, said housing comprising:

(a) a first side that includes a plurality of ports enabling said pump module to be controllably connected to said control module, and to be in fluid communication with each reactant supply source; and

(b) a second side that includes a plurality of ports enabling said pump module to be in fluid communication with said first reaction module.

25. The modular system of Claim 4, wherein a quantity of said desired chemical product produced by the modular system is increasable by at least one of:

(a) replacing said pump module with a different pump module having an increased flow rate;

(b) replacing said replaceable reactor in said first reaction module with a different replaceable reactor that is configured to provide an increased rate of production of the desired chemical product; and

(c) replacing said first reaction module with a different reaction module that is configured to provide an increased rate of production.

26. The modular system of Claim 4, wherein all connections between modules are achieved using quick connect connectors that enable rapid connection and disconnection of the modules.

27. A modular system that is readily reconfigurable to produce a desired chemical product from a plurality of reactants, comprising:

(a) a control module, said control module comprising a memory, a processor, and a user interface, the memory storing machine instructions that are executable by the processor;

(b) a pump module controllably connected to said control module, said pump module comprising at least one pump and defining a plurality of fluid paths for heat transfer media and for reactants; and

(c) a reaction module in fluid communication with the pump module, said reaction module defining a plurality of fluid paths for heat transfer media, reactants, and a product fluid path and including a removable reactor, said reactor comprising:

- (i) a plurality of reactant inlets;
- (ii) a mixing volume in which the plurality of reactants are first mixed together;
- (iii) a reaction volume in which the plurality of reactants combine to form the desired chemical product; and
- (iv) a product outlet for removing the desired product from the microreactor.

28. The modular system of Claim 27, wherein the reactor comprises a microreactor.

29. The modular system of Claim 27, further comprising a residence time module that is in fluid communication with the product outlet of said reaction module and which provides an extended time for the reaction of the reactants to complete.

30. A modular system that is readily reconfigurable to produce a desired chemical product from a plurality of reactants, comprising:

- (a) a pump module controls flow of a plurality of fluids through the modular system; and

- (b) a reaction module in fluid communication with the pump module, the reaction module including an environment that promotes production of the desired chemical product from the plurality of reactants within a replaceable reactor that is disposed within the reaction module, said replaceable reactor being selected from among a plurality of different replaceable reactors, based upon it having a configuration that is able to produce the desired chemical product.

31. The modular system of Claim 30, wherein the reactor comprises a microreactor.

32. The modular system of Claim 31, wherein the microreactor comprises:

- (a) a heat exchanger;
- (b) a plurality of reactant inlets;
- (c) a mixing volume in which the plurality of reactants are mixed together;
- (d) a reaction volume in which the reactants combine to form the desired chemical product; and
- (e) a product outlet for removing the desired product from the microreactor.

33. The modular system of Claim 30, further comprising a control module controllably connected to the pump module and the reaction module, said control unit module monitoring and automatically controlling production of the desired chemical product by the modular system.

34. The modular system of Claim 33, wherein the control module comprises a memory, a processor, and a user interface, said memory storing machine instructions that are executed on the processor to enable the control module to monitor and automatically control production of the desired chemical product.

35. The modular system of Claim 34, wherein the machine instructions include a plurality of different instruction sets, each different instruction set enabling the control module to monitor and automatically control the production of a different desired chemical product, said machine instructions executed by the processor enabling a user to select an instruction set to produce a specific desired chemical product with the user interface.

36. The modular system of Claim 33, wherein control module comprises a personal computer system.

37. The modular system of Claim 33, wherein the pump module comprises:

- (a) at least one pump controllably connected to the control module;
- (b) a data bus and a power bus electrically connected to the control module;
- (c) a plurality of heat transfer media fluid paths; and
- (d) a plurality of reactant fluid paths.

38. The modular system of Claim 37, wherein the plurality of heat transfer media fluid paths comprise:

- (a) at least one heat transfer media inlet, at least one heat transfer media fluid passage in fluid communication with each heat transfer media inlet, and at least one heat transfer media outlet in fluid communication with each heat transfer media fluid passage; and
- (b) at least one spent heat transfer media inlet, at least one spent heat transfer media fluid passage in fluid communication with each spent heat transfer media inlet, and at least one spent heat transfer media outlet in fluid communication with each spent heat transfer media fluid passage.

39. The modular system of Claim 38, wherein the plurality of reactant fluid paths comprise:

- (a) a plurality of individual reactant inlets;
- (b) an individual reactant fluid passage in fluid communication with each individual reactant inlet and said at least one pump; and
- (c) an individual reactant outlet in fluid communication with each individual reactant fluid passage.

40. The modular system of Claim 39, wherein the pump module further comprises a solvent inlet selectively in fluid communication with an individual reactant fluid passage.

41. The modular system of Claim 40, wherein the pump module further comprises a plurality of valves controllably connected to said control module, at least one valve of said plurality of valves being operable in a first valve position that enables the solvent inlet to be in fluid communication with an individual reactant fluid passage, and a second valve position that disables said fluid communication between said solvent inlet and said individual reactant fluid passage, said second valve position also enabling an individual reactant inlet to be in fluid communication with said individual reactant fluid passage.

42. The modular system of Claim 39, further comprising a replaceable filter element to prevent the flow of particulates through a selected individual reactant outlet.

43. The modular system of Claim 42, further comprising a pressure sensor to monitor an operational status of said replaceable filter element.

44. The modular system of Claim 38, wherein the pump module includes a pump for controlling heat transfer media flow through the modular system.

45. The modular system of Claim 39, wherein said pump module includes a pump for controlling reactant fluid flow through the modular system.

46. The modular system of Claim 40, wherein the pump module further comprises a housing, said housing having a first side and a second side, said housing enclosing said at least one pump, said data bus, said power bus, said plurality of heat transfer media fluid paths; and said plurality of reactant fluid paths.

47. The modular system of Claim 46, wherein said first side of the housing comprises:

(a) a first data interface port electrically coupled to said data bus, said first data interface port being adapted to electrically connect to said control module;

(b) a first power interface port electrically coupled to said power bus, said first power interface port being adapted to electrically connect to said control module;

(c) at least one heat transfer media inlet port in fluid communication with said at least one heat transfer media fluid passage, said at least one heat transfer media inlet port being adapted to connect in fluid communication with a heat transfer media fluid supply;

(d) at least one spent heat transfer media outlet port in fluid communication with said at least one spent heat transfer media fluid passage, said at least one spent heat transfer media outlet port being adapted to connect in fluid communication with a spent heat transfer media fluid collection reservoir;

(e) a plurality of individual reactant inlet ports, each individual reactant inlet port being in fluid communication with a different individual reactant fluid passage, each individual reactant inlet port being adapted to connect in fluid communication with a separate reactant fluid supply; and

(f) a solvent inlet port in fluid communication with said individual reactant fluid passages, the solvent inlet port being adapted to connect in fluid communication with a solvent fluid supply.

48. The modular system of Claim 46, wherein said second side of the housing comprises:

(a) a second data interface port electrically coupled to said data bus, said second data interface port being adapted to electrically connect to said reaction module;

(b) a second power interface port electrically coupled to said power bus, said second power interface port being adapted to electrically connect to said reaction module;

(c) at least one heat transfer media outlet port in fluid communication with said at least one heat transfer media fluid passage, said at least one heat transfer media outlet port being adapted to connect in fluid communication with said reaction module;



(d) at least one spent heat transfer media inlet port in fluid communication with said at least one spent heat transfer media fluid passage, said at least one spent heat transfer media inlet port being adapted to connect in fluid communication with said reaction module; and

(e) a plurality of individual reactant outlet ports, each individual reactant outlet port being in fluid communication with a different individual reactant fluid passage, each individual reactant outlet port being adapted to connect in fluid communication with said reaction module.

49. The modular system of Claim 47, wherein the first data interface port and the first power interface port are adapted to be rapidly coupled and uncoupled to said control module, and wherein the heat transfer media inlet, the spent heat transfer media outlet, and the plurality of reactant inlet ports are adapted to be rapidly coupled and uncoupled respectively with said heat transfer media fluid supply, said spent heat transfer media fluid collection reservoir, and each separate reactant fluid supply.

50. The modular system of Claim 48, wherein the second data interface port and the second power interface port are adapted to be rapidly coupled and uncoupled to said reaction module, and the heat transfer media outlet, the spent heat transfer media inlet, and the plurality of reactant outlet ports are adapted to be rapidly coupled and uncoupled to said reaction module.

51. The modular system of Claim 33, wherein the reaction module further comprises:

- (a) a data bus and a power bus electrically connected to the pump module;
- (b) a plurality of heat transfer media fluid paths;
- (c) a plurality of reactant fluid paths; and
- (d) a product fluid path.

52. The modular system of Claim 51, wherein the plurality of heat transfer media fluid paths comprise at least one heat transfer media inlet, at least one heat transfer media fluid passage in fluid communication with each heat transfer media inlet, at least one heat transfer media outlet in fluid communication with each heat transfer media fluid line, at least one spent heat transfer media inlet, at least one spent heat transfer media fluid passage in fluid communication with each spent heat transfer media inlet, and at least one spent heat transfer media outlet in fluid communication with each spent heat transfer media fluid passage.

53. The modular system of Claim 51, wherein the plurality of reactant fluid paths comprise a plurality of individual reactant inlets, and an individual reactant fluid passage in fluid communication with each individual reactant inlet and with said reactor.

54. The modular system of Claim 51, wherein the product fluid path comprises a product outlet in fluid communication with said reactor.

55. The modular system of Claim 51, wherein the reaction module further comprises a housing, said housing having a first side adapted to be connected to said pump module, and a second side opposite said first side, said housing enclosing said reactor, said data bus, said power bus, said plurality of heat transfer media fluid paths; said plurality of reactant fluid paths, and said product fluid path.

56. The modular system of Claim 55, wherein said first side of the housing comprises:

(a) a first data interface port electrically coupled to said data bus, said first data interface port being adapted to connect electrically to said pump module;

(b) a first power interface port electrically coupled to said power bus, said first power interface port being adapted to connect electrically to said pump module;

(c) at least one heat transfer media inlet port in fluid communication with said at least one heat transfer media fluid passage, said at least one heat transfer media inlet port being adapted to connect in fluid communication with said pump module;

(d) at least one spent heat transfer media outlet port in fluid communication with said at least one spent heat transfer media fluid passage, said at least one spent heat transfer media outlet port being adapted to connect in fluid communication with said pump module; and

(e) a plurality of reactant inlet ports, each individual reactant inlet port being in fluid communication with said individual reactant fluid passage, each individual reactant inlet port being adapted to connect in fluid communication with said pump module.

57. The modular system of Claim 55, wherein said second side of the housing comprises:

(a) a second data interface port electrically coupled to said data bus, said second data interface port being adapted to connect electrically to an optional additional processing module;

(b) a second power interface port electrically coupled to said power bus, said second power interface port being adapted to connect electrically to said optional additional processing module;

(c) at least one heat transfer media outlet port in fluid communication with said at least one heat transfer media fluid passage, said at least one heat transfer media outlet port being adapted to connect in fluid communication with said optional additional processing module;

(d) at least one spent heat transfer media inlet port in fluid communication with said at least one spent heat transfer media fluid passage, said at least one spent heat transfer media inlet port being adapted to connect in fluid communication with said optional additional processing module; and

(e) a product outlet port, said product outlet port being in fluid communication with said reactor, said product outlet port being adapted to connect in fluid communication with one of said optional additional processing module and a product collection reservoir.

58. The modular system of Claim 33, further comprising at least one additional processing module, said at least one additional processing module being in fluid communication with and electrically coupled to said reaction module.

59. The modular system of Claim 58, wherein said at least one additional processing module comprises a residence time module.

60. The modular system of Claim 59, wherein said residence time module comprises a capillary passage in fluid communication a product outlet port of said reaction module, and a heat exchanger in fluid communication with said reaction module.

61. The modular system of Claim 60, wherein said residence time module further comprises a proportional valve in fluid communication with said capillary passage, said proportional valve being controllably connected to said control module.

62. The modular system of Claim 33, wherein said modular system comprises a plurality of heat transfer media fluid paths, and said plurality of heat transfer media fluid paths are configured in one of a parallel fluidic system and a serial fluidic system.

63. A method for processing a plurality of reactants to produce a desired chemical product, comprising the steps of:

(a) providing a plurality of modules that are adapted to be readily reconfigurable into a modular system, said plurality of modules including:

(i) a control module;

(ii) a pump module controllably connected to said control module, said pump module comprising at least one pump to pump a fluid through the modular system;

(iii) a reaction module in fluid communication with the pump module, said reaction module including a reactor;

(iv) a supply of each of said plurality of reactants; and

(v) a heat transfer media supply;

(b) assembling a modular system from said plurality of modules, using the modules that are suitable to produce the desired chemical product; and

(c) causing the control module to automatically control the plurality of modules so as to establish a desired flow rate of said plurality of reactants into said modular system, said plurality of reactants combining in said reactor to produce said desired chemical product.

64. The method of Claim 63, further comprising the step of increasing a production capacity of said modular system by replacing the pump module with a different pump module capable of generating a higher flow rate.

65. The method of Claim 63, wherein the reactor comprises a microreactor.

66. The method of Claim 63, further comprising the step of replacing said reactor with a different reactor, to enable said modular system to produce a different desired chemical product.

67. The method of Claim 63, further comprising the step of increasing a residence time of the desired chemical product within said modular system to provide sufficient time for a desired reaction between said plurality of reactants to occur.

68. The method of Claim 63, further comprising the step of reconfiguring the modular system to increase a production capacity of said modular system by replacing the reaction module with a different reaction module capable of accommodating a higher flow rate.

69. A method for processing at least one reactant to produce a desired chemical product, comprising the steps of:

(a) providing a plurality of modules that are adapted to be readily reconfigurable into a modular system, said plurality of modules including:

(i) a control module;

(ii) a pump module controllably connected to said control module, said pump module comprising at least one pump adapted to pump a fluid through the modular system;

(iii) a reaction module in fluid communication with the pump module, said reaction module including a reactor;

(iv) a supply of each reactant used; and

(v) a heat transfer media supply;


(b) assembling a modular system from said plurality of modules, using the modules that are suitable to produce the desired chemical product; and

(c) causing the control module to automatically control the plurality of modules so as to establish a desired flow rate of said at least one reactant into said modular system, said at least one reactant reacting in said reactor to produce said desired chemical product.

70. A modular system that is readily reconfigurable to produce a desired chemical product from at least one reactant, comprising:

(a) a pump module that controls flow of a plurality of fluids through the modular system; and

(b) a reaction module in fluid communication with the pump module, the reaction module including an environment that promotes production of the desired chemical product from said at least one reactant within a replaceable reactor that is disposed within the reaction module, said replaceable reactor being selected from among a plurality of different replaceable reactors, based upon it having a configuration that is able to produce the desired chemical product.



71. A modular system for producing a desired chemical product from at least one reactant, comprising:

(a) a control module, said control module being adapted to monitor and control production of the desired chemical product by the modular system;

(b) a reactant supply source for each reactant used, a flow of each reactant used from its reactant supply source being controlled by the control module; and

(c) a first reaction module in fluid communication with at least one reactant supply source to receive said at least one reactant, said first reaction module being controllably connected to said control module and including a replaceable reactor, said replaceable reactor automatically producing the desired chemical product from said at least one reactant under the control of the control module.